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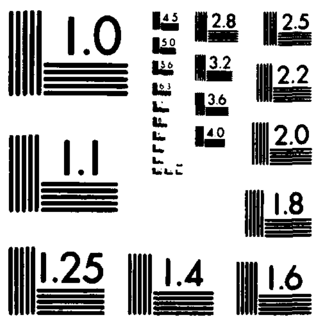
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PLASMA INJECTION FOR A SHIVA MACHINE

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January 1980

Final Report

Approved for public release; distribution unlimited.

AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base, NM 87117

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This technical report has been reviewed and is approved for publication.

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A plasma beam produced by a plasma gun of the Cheng type is used to explore a new method of injecting a densed fully ionized plasma in a Shiva machine. In preliminary experiments the beam was injected through a hole drilled in a metal plate to simulate the backplate of the compression chamber of the Shiva machine. Preliminary measurements by an Ashby-Jephcott laser interferometer indicate that densities close to $5\times10^{18}/cm^3$ can be produced in the compression chamber.

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Introduction

The concept of substituting the "liner" foil in SHIVA implosion chambers by plasma injected from a subsidiary gun had been proposed a few years ago by M. Wolfe*. In order to test the feasibility of this idea, a series of investigations was performed in which plasma produced by a coaxial gun of the Cheng type (Ref. 1) was to be introduced in a container analogous to the implosion chamber.

Because the plasma had to be injected through a number of circular holes whose centers were arranged on a circle, there was some concern about the influence of the non-uniform distribution in the azimuthal direction of the plasma density. To evaluate the extent of this non-uniformity it was decided to study the behavior of the plasma as it is injected through a circular orifice in a flat plate and to compare it with the behavior of the plasma as it escapes from the two neighboring holes.

This report summarizes the results obtained and reports on the preliminary measurements of electron densities and on photographic observations of the plasma jet.

Criteria for Plasma Densities

The required densities were found from the assumption that 1 mg of plasma for the MJB or 100 μg for the 100 KJB was to be injected inside the implosion chamber. The plasma was to be introduced through

1. Cheng, D. Y., "Deflagration Waves in Pulsed Plasma Accelerators," Bull. Am. Phys. Soc. 13, 1560, 1968.

*M. Wolfe, private communication. Wolfe unfortunately never had an opportunity to test his idea since he died in an accident.

90 holes, each 1 cm in diameter and aligned on a circle of 20 cm in radius. The implosion chamber is 2 cm in height. It is important, therefore, that the plasma be uniform in the axial direction and not recombine during the filling time.

The number densities required for the interaction chamber satisfying the above conditions are shown in Table 1.

TABLE 1

Number Densities

Density	MJB (1 mg)	100 KJB (100 μg)
Hydrogen	4.23×10^{18} cm^{-3}	4.23×10^{17} cm^{-3}
Helium	1.06×10^{18} cm^{-3}	1.06×10^{17} cm^{-3}
Argon	1.57×10^{17} cm^{-3}	1.57×10^{16} cm^{-3}
Copper	6.66×10^{16} cm^{-3}	6.66×10^{15} cm^{-3}

Now, the characteristic radiation cooling time is given by $\tau = \frac{n_e k T_e}{W}$ where W, the radiation power per unit volume, is composed of the free - free transitions and free-bound transitions. Actually,

$$W = W_{ff} + W_{fb}$$

$$= (1.52 \times 10^{-32}) n_e^2 T_e^{\frac{1}{2}} + (4.11 \times 10^{-31}) n_e^2 T_e^{-\frac{1}{2}} \text{ in W/cm}^3$$

In the above relation n_e is the electron density per cm^3 and T_e is in eV. The temperature thus falls like $T_e = T_{initial} \exp(-\frac{t}{\tau})$.

Now, if we require $v_{th} = 0.01 v_{directed}$ in the implosion chamber and $v_{direct} = 10$ cm/μs, then

$$v_{th} = \left(\frac{2T_e}{m_e}\right)^{\frac{1}{2}} = 0.01 v_{direct} = 10^5 \text{ cm/s}$$

This defines

$$T_e = \frac{1}{2} m_e \times 10^{10}$$

$$= T_{init.} \exp\left(-\frac{t}{\tau}\right)$$

Hence, for a given initial $T_{init.} \simeq 10$ eV, the time needed to allow the temperature to cool to Te ≃ 3 eV is of the order of 1 μs.

The density n_e needed above to satisfy the requirement that the plasma will not recombine during the time the plasma fills the interaction chamber indicates that one would need a density of at least 10^{17} cm^{-3} (for He).

Summary of Diagnostics Performed

The SHIVA implosion chamber was simulated by two parallel plates. One of the plates had a hole 1 cm in diameter. In a subsequent experiment the perforated plate was replaced with one which had two holes.

The important parameters that were needed to be measured were: the directed velocity of the plasma prior to its impinging on the plate, its velocity after its escaping through the orifice in the plate, the extent of divergence of the plasma jet as it leaves the plate and the density of the plasma in these various conditions.

The velocities of the plasma were inferred from an STL image converter camera used in a streaking mode. The divergence of the beam was directly seen from the STL camera used as a frame camera. The plasma density was measured by means of an Ashby-Jephcott (Ref. 2) laser interferometer used directly as developed by Ashby and Jephcott or as modified by Bekefi (Ref. 3). The first method

2. Ashby, D. E. T., et al., "Performance of the He-Ne Gas Laser as an Interferometer for Measuring Plasma Density," J. Appl. Phys. 36, 29, 1965.

3. Hopper, E., and Bekefi, G., "Laser Interferometry for Repetitively Pulsed Plasmas," J. Appl. Phys. 37, 4083, 1966.

is suited for higher density range in which the interferometer yields several fringes, while the other is specially suited when one detects a fraction of a fringe.

Results

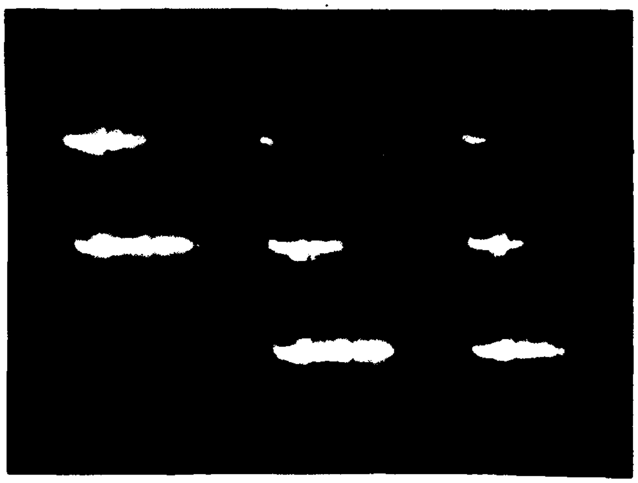
The beam velocity was observed to be approximately 5 to 10 cm/μs (Fig. 1). This higher velocity works to our advantage since the transit time of the plasma over a length equal to the height of the implosion chamber is much shorter than the recombination time of the plasma.

(a) (b) (c)

T_1

T_2

T_3



(T_1, T_2, T_3) = (3,2,5) μsec (1,2,2) μsec (1,1,1) μsec

Figure 1. Plasma beam at different framing sequences. (t_1, t_2, t_3) are delays in μsec between frames. t_1 is the initial time delay with respect to the beams first appearance at the muzzle of the gun (V_0 = 9.0 kV).

Al or Cu plates, 6.25 mm in thickness, are used for the plates. It was found that it was important to electrically float the plates. Where grounded, appreciable return currents flow to the ground. These currents, if asymmetric, cause the plasma beam to acquire a whipping motion.

Several fringes were detected on the interferometer (Fig. 2) thus indicating that the beam electron density is quite high. In fact, we estimated it to be at least 5×10^{17} cm^{-3} at a distance of 10 cm away from the muzzle of the gun. This is also the location of the plate with the hole.

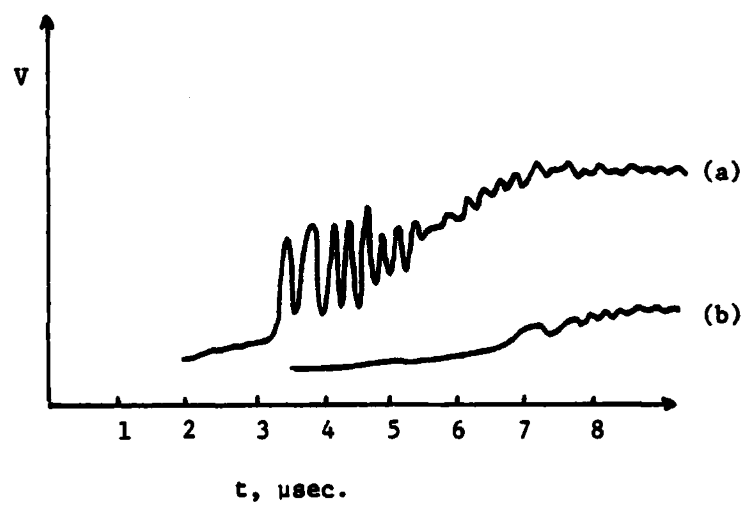


Figure 2. Interferometer output for the plasma beam:

a) with plasma

b) without plasma

Some of the Al (or Cu) lines are very close to the He-Ne laser line, thus masking the He-Ne laser line and preventing interferometric density measurements of the plasma beam after passing through the hole in the plate.

Visual observation of the appearance of the plate revealed that the plate was seriously ablated (Fig. 3). It thus appeared that an appreciable amount of metal vapor is injected in the implosion chamber together with the plasma.

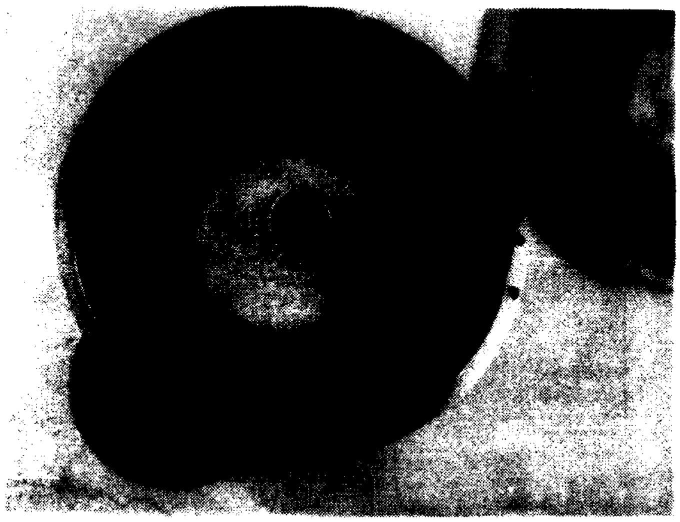


Figure 3. Al plate after 5 shots. Ablation of the plate surface and the hole is clearly visible.

The density of ablatants can best be found from the respective measurement of intensities of radiation of Al (for an Al plate) or Cu lines. These necessitate narrow band interference filters to differentiate these lines from the other lines.

Since we did not have such filters in our laboratory, we estimated the ablatant density from the mass of material ablated. This estimate yielded the remarkable result that about $\sim$ mg of Al per shot appeared to be entrained by the plasma for each shot. Such a high ablation of the plate material may thus lower the restriction of the higher densities initially estimated for filling the interaction chamber with plasma.

The preliminary results described here show that plasma injection is most promising.